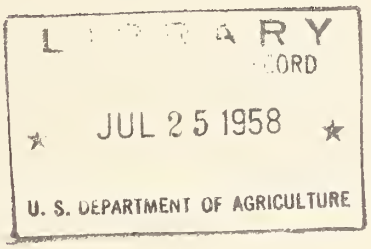
UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Cotton Division



GRADE AND COLOR INDEXES DEVELOPED FOR EVALUATING RESULTS OF USDA COTTON FINISHING TESTS

By Dorothy Nickerson, Cotton Technologist
and Franklin E. Newton, Cotton Technologist

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Three years of chemical finishing data are now available on the Annual Quality Studies (1), (2), (3), (4) published by the Cotton Division of the Agricultural Marketing Service, U. S. Department of Agriculture, and an analysis of these data is needed for making an evaluation that will relate the results both to the cotton standards and to significant cotton quality factors that have been measured for the cottons tested.

Color of the bleached and dyed yarns related to color of the raw stock and/or grey yarns used in processing provide one direct basis for quality evaluation of these finishing tests. Uniformity of color processing is also important, but these first studies are confined to yarn color evaluation.

Color measurements made in the laboratories of the Cotton Division are in terms of the R_d and b scales of Hunter's colorimeters. Raw cotton is measured on the Nickerson-Hunter Cotton Colorimeter, an automatic, self-standardizing electronic instrument that converts color directly to terms of equivalent grade (figure 1). Yarns, in skein form, are measured on a Gardner Automatic Color-Difference Meter equipped with a specially designed turret top and clamp for holding yarn samples.

There are three scales on the Color-Difference Meter, R_d, a, and b. The R_d scale measures percentage of reflectance from 0 to 100. The b scale provides a measure of yellowness in the direction of +b (as in raw cotton, or grey or bleached yarns) and of blueness in the direction of -b (as in the blue-dyed cotton yarns of the standardized dyeing test), the degree of yellowness or blueness increasing as the scale numbers increase. In effect, the b measurements are used in the cotton work as an indication of saturation. The a scale provides a measure of redness in the direction of +a and greenness in the direction of -a. Since the inclusion of this factor would simply help to indicate hue, which usually remains quite constant in the studies being reported, results for the a scale are not included. If in dyeing tests another color than blue were used, then it might be necessary to report the a factor instead of, or in addition to, the b factor. The color data are directly indicated on the Cotton Colorimeter in terms of a two-dimensional plot of R_d (vertical) against b (horizontal).

Since color has more than one dimension it does not lend itself directly to any simple one-dimensional statistical treatment. In order to use color as a single, or a dependent, variable in statistical analyses it would be very convenient if the two- or three-dimensional color results could be reduced to a set of related indexes, each one a single-number expression for the color, or for the color differences, between the samples used in each of the forms studied (raw stock, grey, bleached, and dyed yarns).

A parallel problem exists in expressing the grade of cotton in a single number. Grade is not a one-dimensional series; it is two-dimensional, for there are high to low grades that may be Gray, White, Spotted, Tinged, or Yellow Stained. Some years ago a common denominator was worked out for the grades in these several color classifications in order that an "average grade" might be calculated, also that grade might be used as a dependent variable in statistical analyses of its relation and dependence on measurable cotton quality characteristics. To make such studies a single-number index was needed, and as a result, the grade index in table 1 was developed. With Middling arbitrarily set at 100, the relative grade relations, whether based

Table 1.--Grade names, symbols, code numbers and index values

Color class	Grade name	Symbols	Code	Grade Index
White * (2)	Good Middling	GM	3 *	105
	Strict Middling	SM	4 *	104
	Middling	M	5 *	100
	Strict Low Middling	SLM	6 *	94
	Low Middling	LM	7 *	85
	Strict Good Ordinary	SGO	8 *	76
	Good Ordinary	GO	9 *	70
Spotted (3)	Good Middling Spotted	GM Sp	33	101
	Strict Middling Spotted	SM Sp	43	99
	Middling Spotted	M Sp	53	93
	Strict Low Middling Spotted	SLM Sp	63	83
	Low Middling Spotted	LM Sp	73	75
Tinged (4)	Good Middling Tinged	GM Tg	34	94
	Strict Middling Tinged	SM Tg	44	91
	Middling Tinged	M Tg	54	82
	Strict Low Middling Tinged	SLM Tg	64	75
	Low Middling Tinged	LM Tg	74	68

* The code (2) for color class which follows the grade number code, is sometimes omitted in reporting the White grades, e.g. either (3) or (32) for GM White. The superscripts used to further identify bales in figures 3 to 6 refer to bale positions 1 to 6 in the White grade boxes, and the letters in the Spotted and Tinged grades refer to bales intended to represent white (W), middle (M) and yellow (Y) color within each grade.

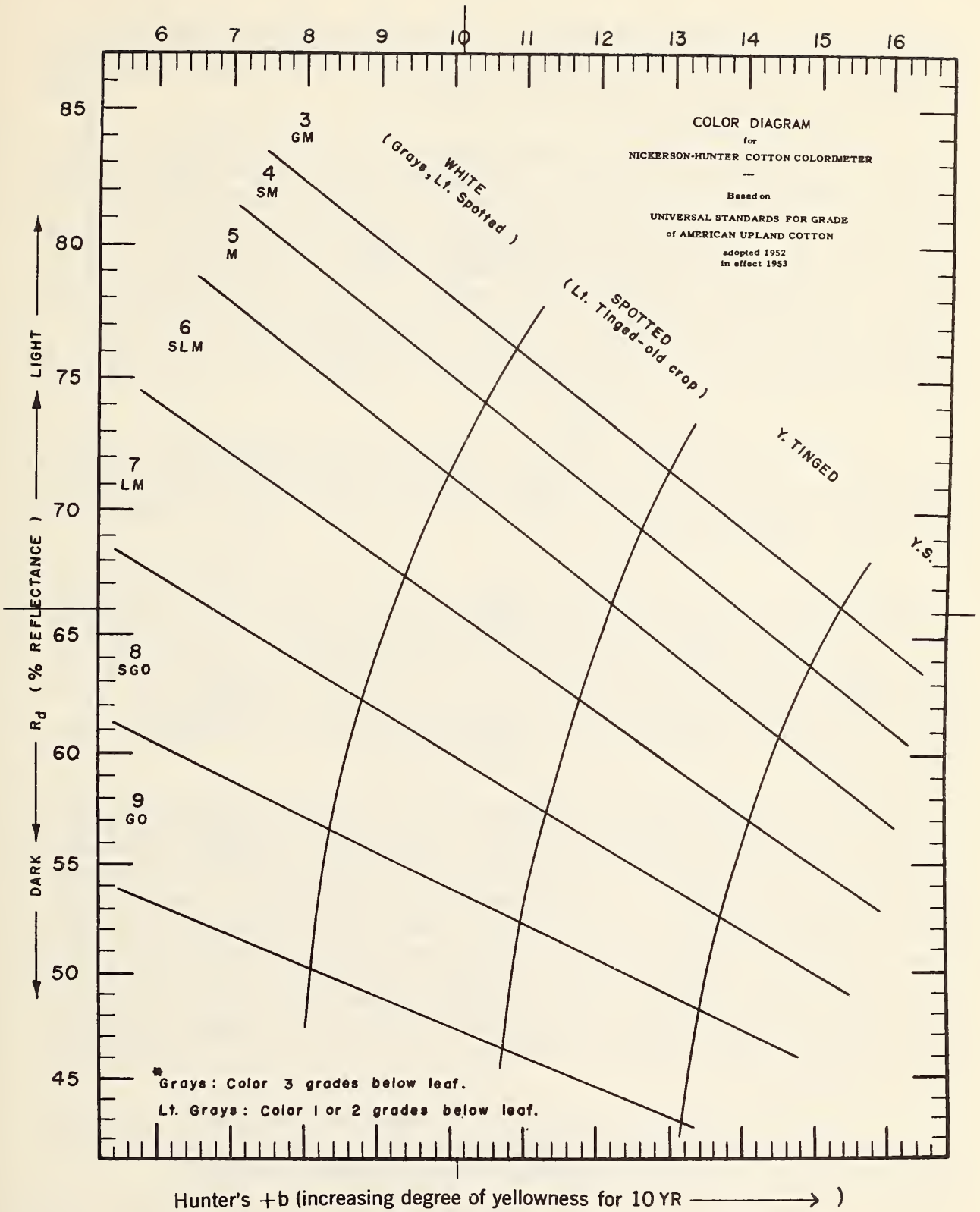

Figure 1.--COLOR DIAGRAM FOR NICKERSON-HUNTER COTTON COLORIMETER illustrating the relationship between color measurements (R_d and b) and equivalent grade color (in terms of the Universal Standards for Grade of American Upland Cotton).

on price 1/ or on color, were found to be as given. When the numbers in table 1 for each grade are entered on the diagram in figure 2 it is possible to check the closeness with which the grade index represents the color relationships in the official cotton grade standards.

This conversion from color measurements of raw stock to a grade index provides a straightforward method of obtaining a single number index for raw cotton. It does not allow full use of the two-dimensional relationships of the grades, and may sometimes even mask their relationships with certain quality factors. However, it does provide a means for making preliminary studies in terms of a one-dimensional scale, studies that later can be extended to include the two-dimensional variations. A similar method has been followed in developing conversion formulas and diagrams for each form of cotton measured for color as a part of the chemical finishing studies of the Cotton Division. In each the index for Middling is held at 100 and that for Good Ordinary is held close to 70.

Color data are shown in figures 3 to 6 for four sets of samples, each set based on results from 55 bales of cotton selected to cover the gamut of the American Upland grade standards. These are in the form of raw stock, grey yarns, bleached yarns, and bleached and blue-dyed yarns, all made from the same series of cottons.

The spread of color for the samples of raw stock and of the grey yarn is wide. The color spread in the bleached yarns is less, and in the dyed form the spread of color begins to fit a single straight line. In order that each set of data shall be treated in the same way, a line of best fit was found by the least squares method and a correlation computed for the R_d and b relationship within each set. The correlation, expressed as r, is shown for each set with its accompanying standard error in figures 3 to 6. The line of best fit is drawn in on each diagram.

The two-dimensional scatter of R_d and b in the raw stock and grey yarns (which makes it possible to differentiate White, Spotted, and Tinged grades as well as grades Good Middling through Good Ordinary) precludes the possibility of any high degree of correlation between the R_d and b color factors. Therefore, as expected, no significant single straight line correlation was found to exist between R_d and b either for raw stock or for grey yarn color. While it might be expected that bleaching would reduce all 55 samples close to a single color and thus provide a closer correlation between R_d and b for the bleached yarns, it was found that after bleaching the color spread still bears considerable relation to the spread of color in the raw stock and in the grey yarn. When it comes to the dyed yarns (dyed after bleaching) the

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1/ Based on average annual prices on designated markets for the various grades during the years 1937-38-39, but showing also a remarkably close agreement to the color relationships of the 1953 grade standards.

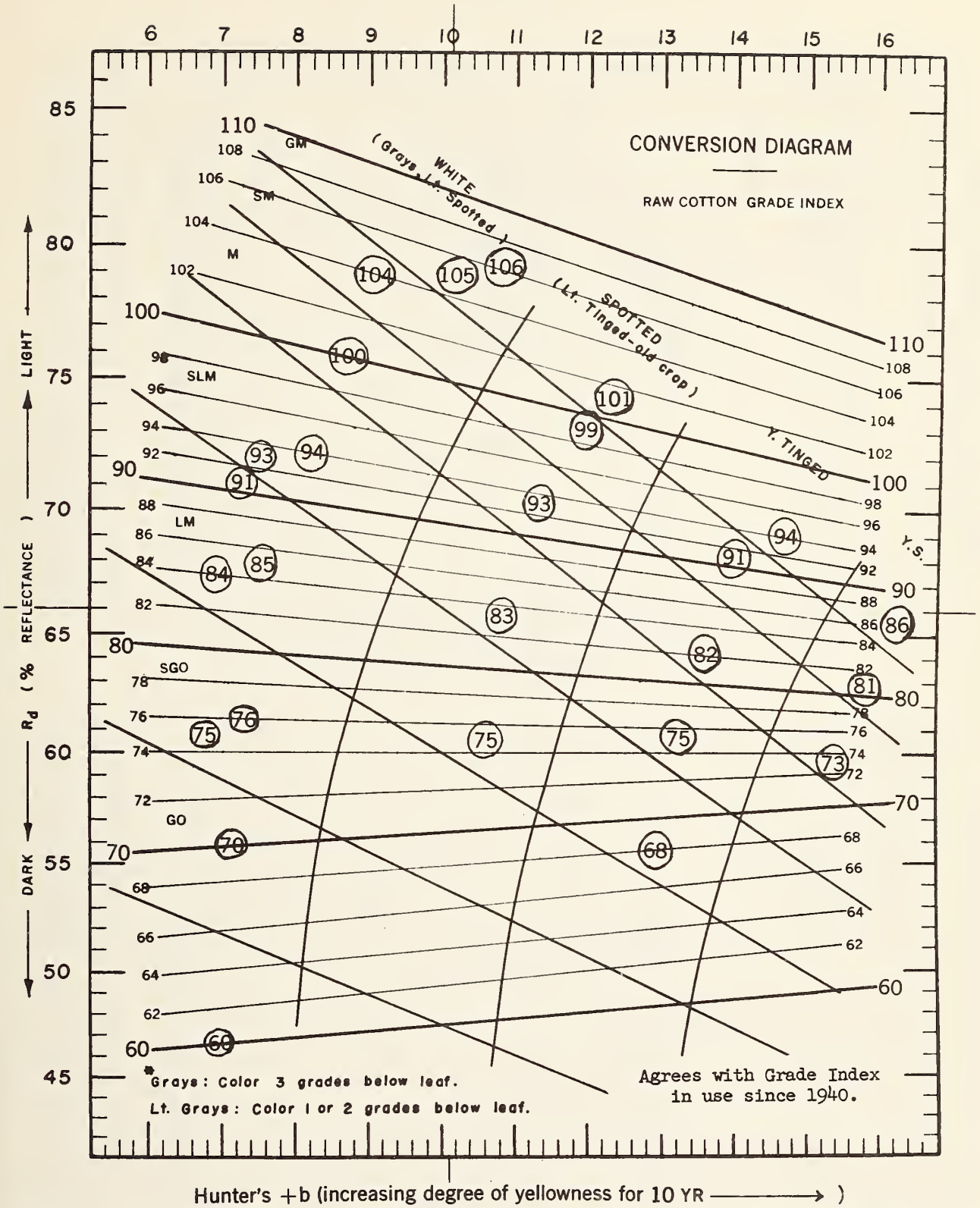

FIGURE 2.--LINES OF EQUAL GRADE INDEX AGAINST A COLOR DIAGRAM OF THE COTTON GRADE STANDARDS. The circled numbers represent index values from table 1 plotted within the color blocks of appropriate grades. Except for the Gray grades, these index numbers fall well within the color limits of appropriate grades (many close to the center of the grade). This diagram indicates the closeness with which the grade index (based on price) relates to the color of the official cotton grade standards.

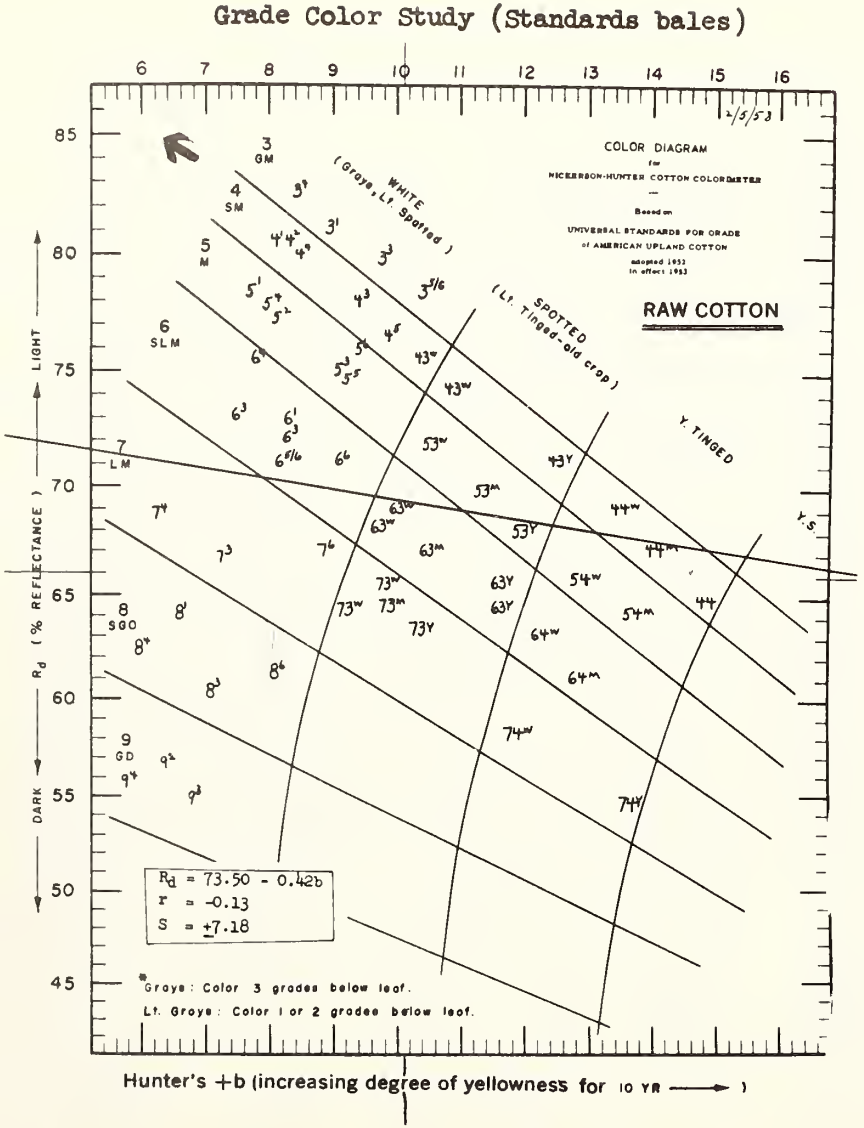

Figure 3.--Color of 55 bales of raw cotton, GM to GO and White to Yellow Tinged. The scatter of samples is so great that there is no significant fit to a single line. The heavy arrow points in the direction of White. Identifying numbers refer to the grade code in table 1.

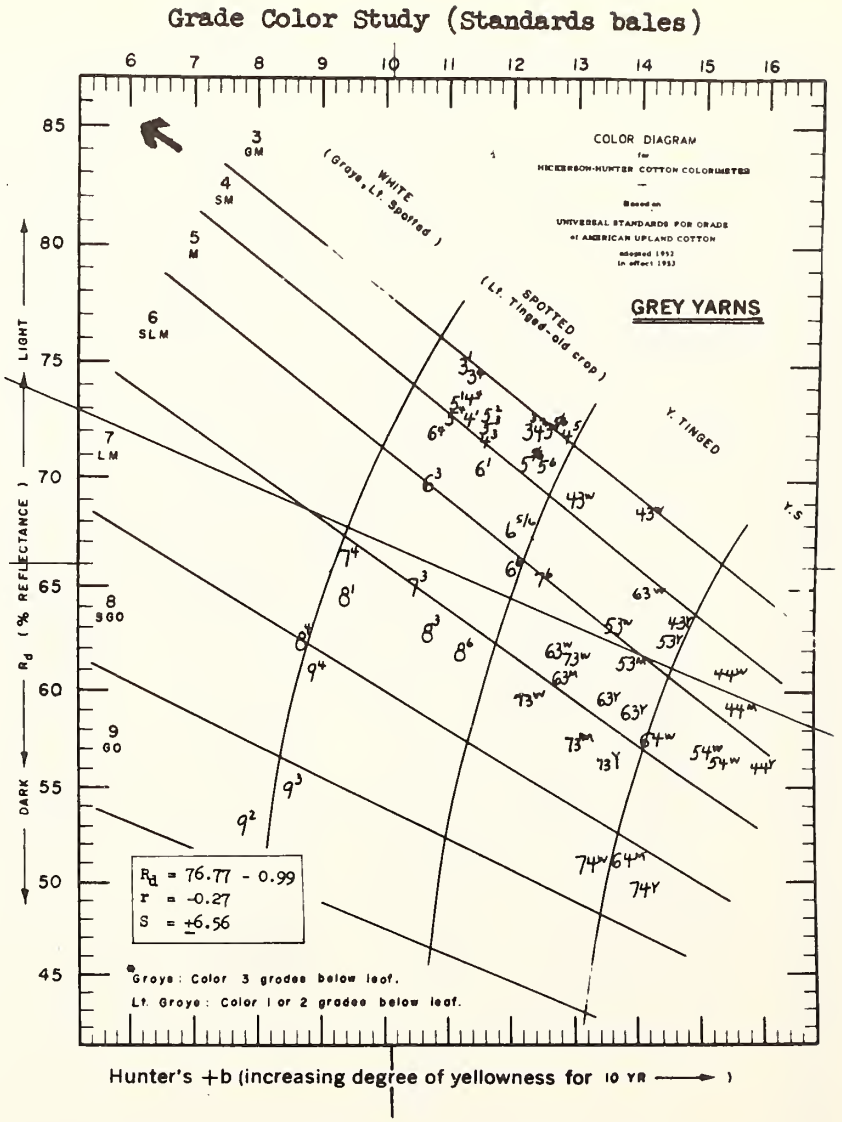

Figure 4.--Color of 22s yarns made from the cottons shown in figure 3. Yarn color shifts toward yellow, and colors are more compressed for high than for low grades. The heavy arrow points in the direction of White.

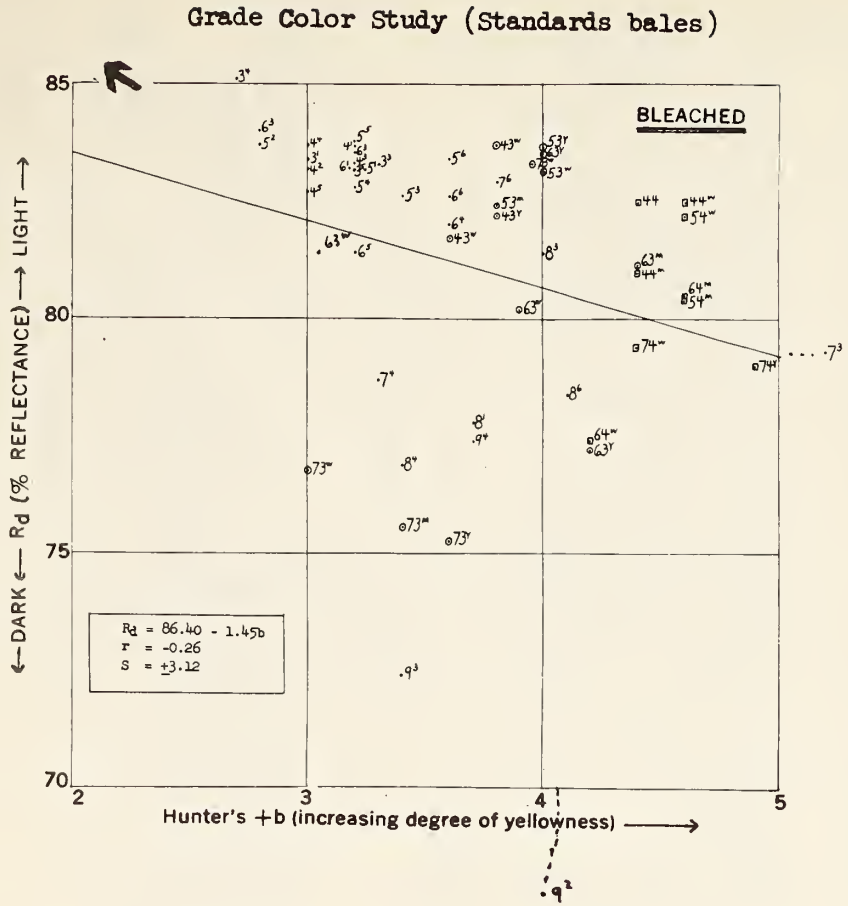

Figure 5.--Color of bleached 22s yarns made from the cottons shown in figure 3. The color has shifted toward White. In general, the higher grade cottons have bleached to a higher reflectance than the lower grades, and Spotted and Tinged cottons have retained more yellow than the White cottons. The heavy arrow points in the direction of White.

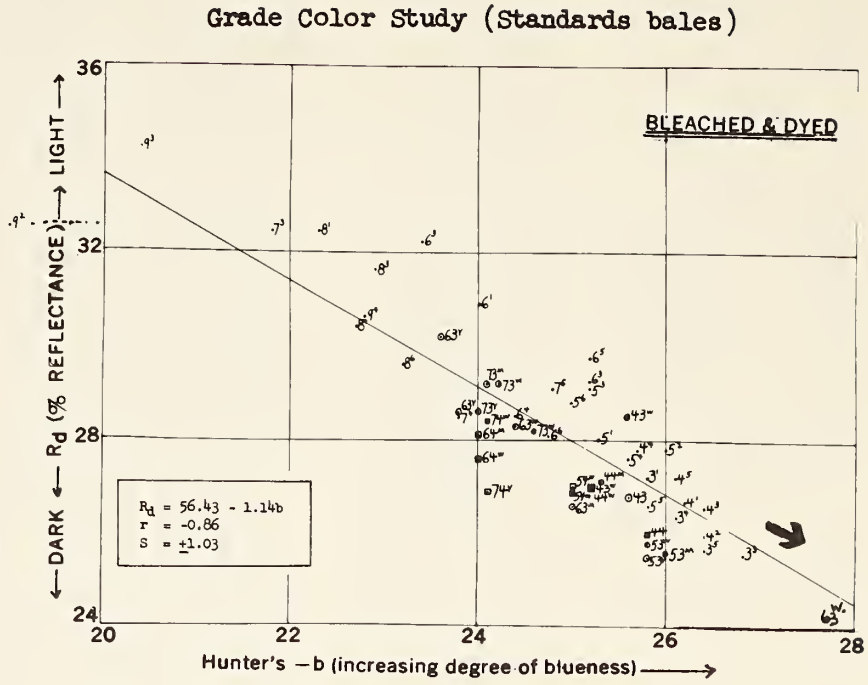

Figure 6.--Color of bleached and blue-dyed 22s yarns made from the cottons shown in figure 3. With few exceptions the high grades have dyed the deepest blue. The heavy arrow points toward a saturated blue.

color spread is reduced enough so that a significant correlation of R_d and b is found around a line of best fit. It is important to keep in mind the fact that the data for each form of yarn studied are based on the same raw stock, and that while there is a better approach in the dyed yarns to a single line fit it is only because the color relations are more compressed than in the raw stock. The data are shown in the same manner for all four sets in order that their relation, and their dependence on each other, may be kept in mind. Numbers used to identify samples in the plotted diagrams are code numbers for the grades.

The grade index of table 1 is shown in figure 2 with lines of constant index number drawn in on the diagram. While these lines are straight they are not parallel, therefore it is easier to obtain the grade index for raw stock directly from a conversion diagram of this sort than to try to find a formula to convert the R_d and b color measurements to an index. Use the diagram in figure 7 to convert R_d and b color measurements of raw stock to the grade index for raw cotton.

To convert color measurements to a grey yarn grade index use the diagram in figure 8. On it a grade diagram is indicated for grey yarns, based on the color data in figure 4. In preparing this diagram the grade index figures of table 1 were entered in the appropriate spaces on the grade diagram, 100 in the center of the Middling block, 94 in the center of Strict Low Middling, 70 at Good Ordinary, with index numbers representing the Spotted and Tinged grades entered in their respective grade spaces. Lines for equal index numbers were then drawn in by the method used in preparing figures 2 and 7. Because these lines of equal index number are straight but not parallel, it is easier to obtain the grey yarn index by use of figure 8 than by use of a formula.

In preparing a diagram (figure 9) for converting color measurements of bleached yarn to a grade index, a somewhat different procedure was used. Since it was no longer clearly evident just how the grade lines should be drawn in, a calculation was made of the average amount of change in R_d and b in the bleached yarn as related to changes in grey yarn color. In bleached yarns each unit change of +b (grey yarn) makes 1.7 more change than a unit change of R_d. This relation was used—holding the level and spread of index values for bleached cottons to 100 for Middling and close to 70 for Good Ordinary—to develop the following formula:

$$\text{Bleached Yarn Grade Index} = 4\left(-20.7 + \frac{R_d}{1.7} - b\right)$$

when: R_d = reflectance of bleached yarn (22s)
b = +b, yellowness of bleached yarn (22s)

The constant (-20.7) places Middling at 100, and the constant (4) spreads the indexes so that Good Ordinary is close to 70. Use figure 9 (or this formula) to obtain the grade index for bleached yarns from R_d and b color measurements. Lines of constant index number are centered on the line that best fits the data in figure 5. To help understand something about the grade relationships involved, the data of figure 5 should be thought of in relation

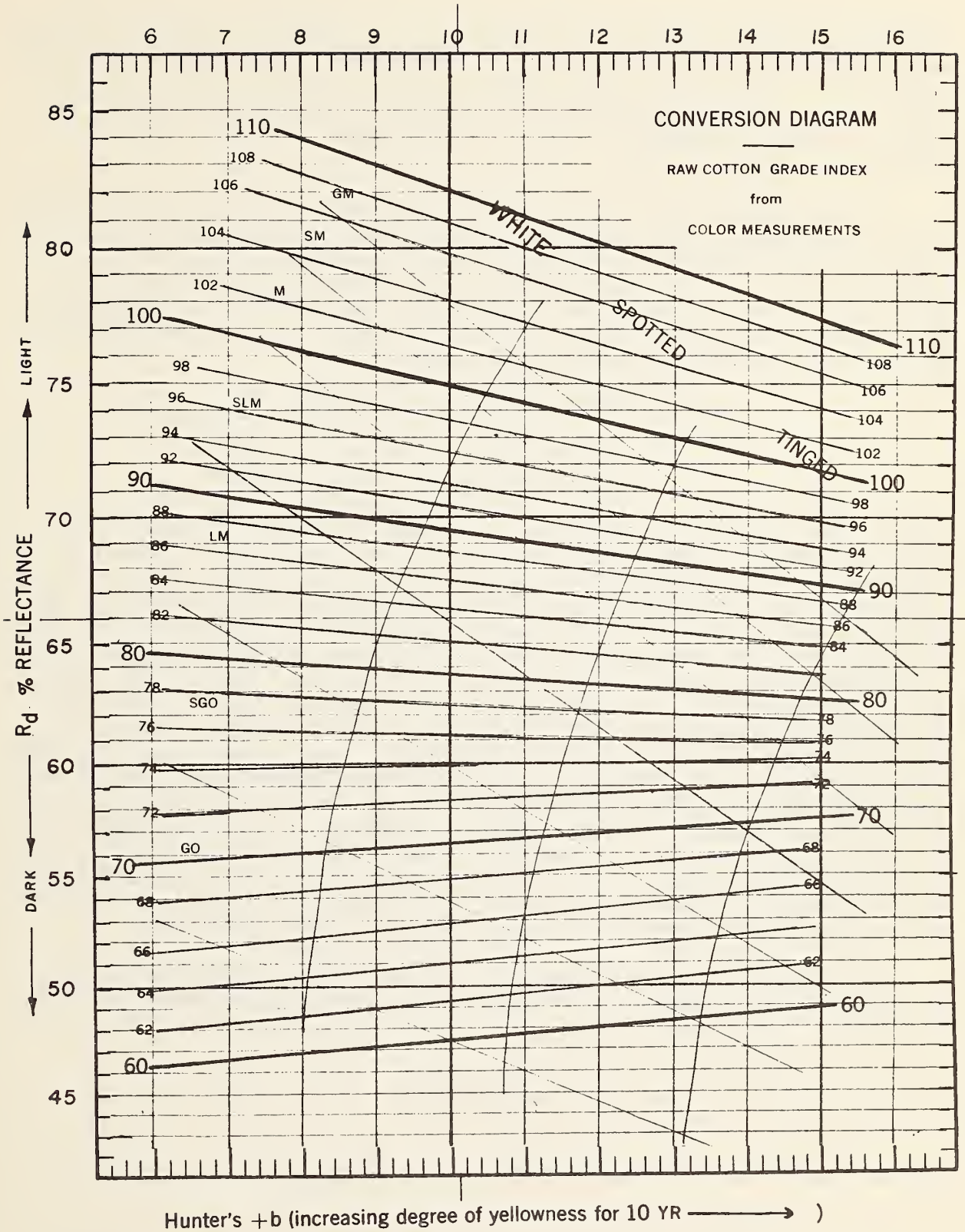

Figure 7.--Diagram for Converting R_d and b measurements of Raw Cotton to a Raw Cotton Grade Index, 60 through 110.

to the conversion diagram of figure 9, for it is upon these data that the conversion diagram is based. At this point in our studies there is no clear way to adjust for the apparently closer relationship that exists between the results for Tinged grades than for White grades, therefore lines of equal index number are left parallel on the diagram, although from a look at the spread of the data in figure 5 there seems no doubt that this is but an approximation of the facts.

Use the diagram in figure 10 to obtain a grade index for dyed yarns from color measurements. This conversion diagram was prepared from the data in figure 6 in a manner similar to that used for developing the index for bleached-yarns. In the yarns dyed after bleaching each unit change of +b (grey yarn) is twice as much as a unit change of R_d. This relationship—placing the index for Middling at 100 and the index for Good Ordinary around 70—was used to develop the following formula:

$$\text{Dyed Yarn Grade Index} = 4\left(13.5 - \frac{R_d}{2} + b\right)$$

when: R_d = reflectance of dyed yarn (22s)
b = -b, blueness of dyed yarn (22s)

The constant (13.5) places Middling at 100 and (4) spreads the results so that the index for Good Ordinary is close to 70. Use figure 10 (or this formula) to obtain the grade index for dyed yarns from R_d and b color measurements. Lines of constant index number are centered on the line that best fits the data in figure 6. Even a quick comparison of figures 6 and 10 indicatesthat on the average the higher grade cottons dye to the deepest color, and therefore have grade index values that are high in comparison to those for low grade cottons. One outstanding exception shows that dyed yarn made from a Strict Low Middling Spotted bale has a higher dyed yarn index than yarns made from any of the Good Middling bales. This is not in error. This particular sample has an unusually high Micronaire reading (5.0) and an unusually low pH (5.7) for such a low grade cotton, but whether these or other factors are responsible for the unusual dye take-up, is not yet known. It is to facilitate the study of relations involved in exceptions of this sort that these grade indexes are so necessary. They will be used in studies of the relationship of quality factors to the finishing properties of cottons, and results will be reported as promptly as they become available.

Table 2 lists color measurements, and the resulting indexes, for the 55 cottons used as a basis for developing the conversion diagrams reported in figures 7 to 10.

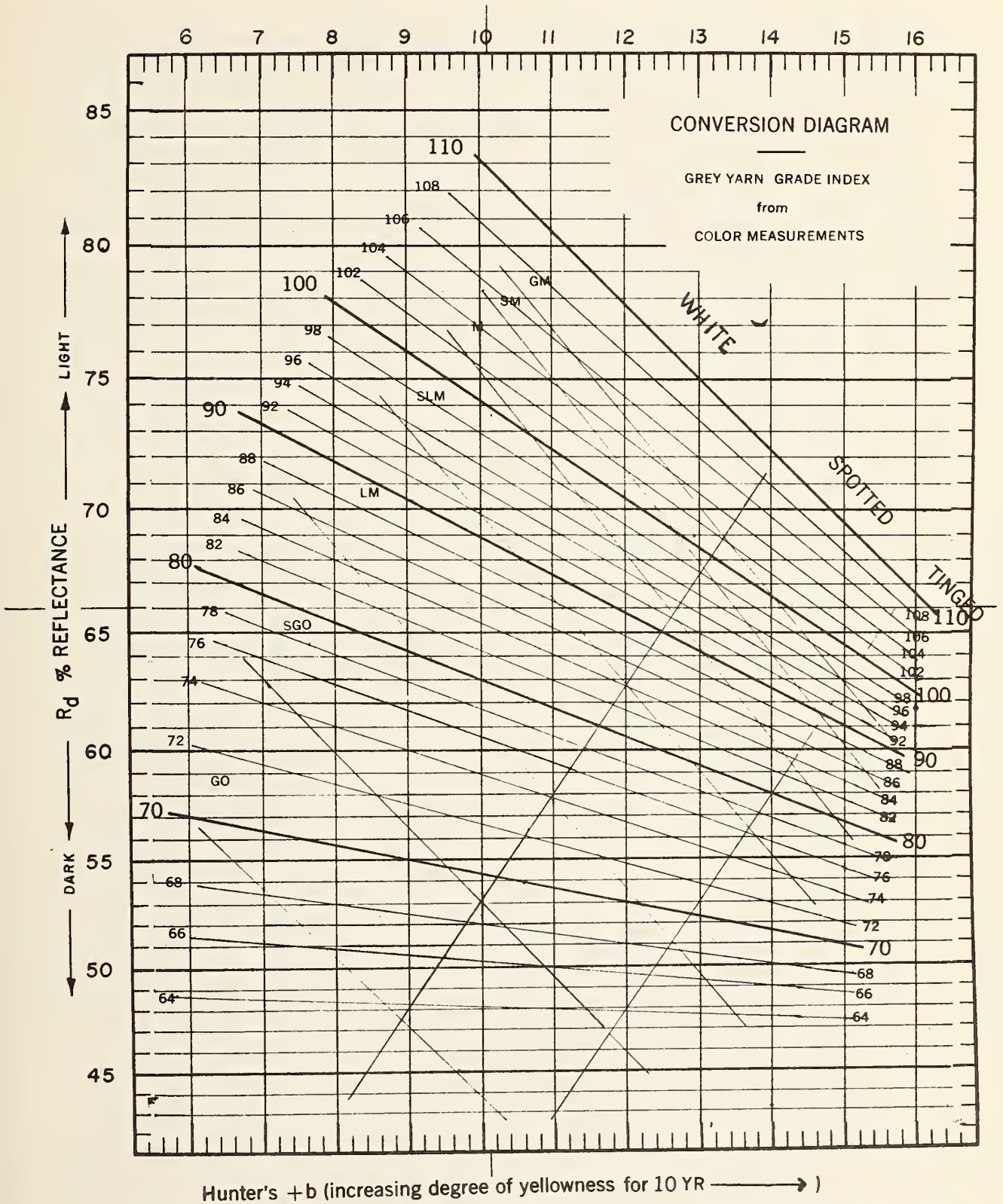

Figure 8.--Diagram for Converting R_d and b measurements of Grey Yarns (22s) to a Grey Yarn Grade Index, 64 through 110.

Table 2.--Data for 55 bales covering the gamut of grades of American Upland cottons. The color data for these samples are used as the basis for developing figures 7-10

Grade by code:		Raw stock			Grey yarn			Bleached yarn			Dyed yarn		
		R_d	b	I_R	R_d	b	I_{Grey}	R_d	b	I_{BL}	R_d	b	$I_{B\&D}$
GM	3^4	82.7	8.5	109	74.5	11.4	104	85.1	2.7	106	26.4	26.1	105
	3^1	81.0	9.0	107	74.9	11.3	105	83.4	3.0	101	27.2	25.8	103
	3	79.8	9.8	106	72.1	12.3	104	83.3	3.3	100	25.6	26.8	110
	$3^{5/}$	78.2	10.5	105	72.1	12.5	105	83.2	3.2	100	25.7	26.4	108
SM	4^1	80.5	8.1	105	72.7	11.3	102	83.7	3.2	101	26.7	26.2	105
	4^2	80.4	8.3	105	72.0	12.4	104	83.2	3.0	101	26.0	26.4	108
	4^4	80.0	8.5	105	74.5	11.3	104	83.7	3.0	102	27.8	25.7	101
	4^3	78.0	9.4	103	71.6	11.5	100	83.3	3.2	100	26.6	26.4	107
	4^5	76.7	9.9	102	72.0	12.8	105	82.7	3.0	100	27.2	26.1	104
SMSp	43(W)	75.6	10.4	101	69.2	13.0	101	81.7	3.6	95	27.0	25.2	101
	43(W)	74.2	10.9	100	68.7	14.1	105	83.7	3.8	99	28.5	25.6	99
	43(Y)	71.2	12.5	96	63.2	14.7	96	82.2	3.8	95	26.8	25.6	103
SMT	44(W)	69.2	13.4	93	61.0	15.4	92	82.5	4.6	93	27.0	25.2	101
	44(M)	67.4	14.0	89	59.6	15.6	89	81.0	4.4	90	27.1	25.3	101
	44	65.0	14.8	84	56.2	16.0	82	82.5	4.4	94	26.0	25.8	105
M	5^1	78.2	7.7	102	73.4	11.1	102	83.2	3.2	100	28.0	25.3	99
	5^4	77.8	8.0	102	72.8	11.0	101	82.8	3.2	99	27.6	25.6	101
	5^2	77.1	8.1	101	72.6	11.5	102	83.7	2.8	103	27.8	26.0	102
	5^3	75.2	9.1	100	72.5	11.5	102	82.6	3.4	98	29.1	25.2	96
	5^5	74.6	9.2	99	70.8	12.2	101	83.8	3.2	101	26.6	25.8	104
	5^6	76.0	9.4	101	70.8	12.4	102	83.4	3.6	99	28.8	25.0	96
MSp	53(W)	71.8	10.5	95	63.2	13.6	90	83.2	4.0	97	25.8	25.8	106
	53(M)	69.9	11.3	92	61.6	13.8	87	82.4	3.8	96	25.6	26.0	107
	53(Y)	68.0	11.9	88	62.6	14.4	90	83.7	4.0	98	25.5	25.8	106
MT	54(W)	65.8	12.8	84	57.8	15.0	82	82.2	4.6	92	27.0	25.0	100
	54(M)	64.2	13.6	82	56.8	15.2	80	80.4	4.6	88	26.9	25.0	100
SLM	6^1	73.0	8.1	95	70.2	11.5	98	83.2	3.2	100	30.9	24.0	88
	6^3	72.0	8.1	94	69.8	10.7	94	83.5	3.2	101	32.2	23.4	83
	6^6	71.1	9.1	93	65.8	12.0	88	82.6	3.6	97	28.1	25.0	98
	6^4	75.6	7.8	99	71.8	10.8	99	82.0	3.6	96	28.5	24.4	95
	6^3	73.0	7.5	95	70.4	11.0	97	84.0	2.8	104	29.2	25.2	96
	$6^{5/6}$	71.0	8.2	92	67.4	12.0	94	81.4	3.2	96	29.8	25.2	95
SLMSp	63(W)	68.2	9.7	87	62.0	12.7	85	80.2	3.9	90	28.3	24.4	95
	63(W)	69.0	10.0	89	65.0	14.0	96	82.0	3.0	98	24.4	28.0	117
	63(M)	67.0	10.5	86	60.6	12.8	82	81.1	4.4	90	26.6	25.0	101
	63(Y)	65.4	11.6	83	59.8	13.5	82	77.2	4.2	82	28.6	23.8	92
	63(Y)	64.7	11.6	82	59.4	13.9	82	83.6	4.0	98	30.2	23.6	88
SLMT	64(W)	63.1	12.2	80	57.2	14.2	79	77.4	4.2	83	27.6	24.0	95
	64(M)	61.2	12.8	76	51.0	13.8	69	80.5	4.6	88	28.1	24.0	94
LM	7^4	68.8	6.3	86	66.4	9.4	84	78.7	3.3	89	28.5	23.8	92
	7^3	66.8	7.3	84	65.0	10.5	85	79.3	5.2	79	32.4	21.8	77
	7^6	67.0	8.9	85	65.4	12.5	91	82.9	3.8	97	29.1	24.8	95
LMSp	73(W)	64.3	9.2	81	61.9	12.9	85	83.3	4.0	97	28.2	24.6	96
	73(W)	65.5	9.8	83	59.3	12.5	79	76.8	3.0	86	29.2	24.2	92
	73(M)	64.5	9.8	81	56.8	12.8	76	75.6	3.4	81	29.2	24.1	92
	73(Y)	63.5	10.3	80	56.2	13.0	75	75.3	3.6	80	28.6	24.0	93
LMT	74(W)	58.6	11.8	72	51.2	13.1	68	79.4	4.4	86	28.4	24.1	93
	74(Y)	55.0	13.6	67	49.8	14.0	68	79.4	4.9	85	26.9	24.1	96
SGO	8^1	64.0	6.6	79	64.4	9.4	81	77.8	3.7	85	32.4	22.3	79
	8^4	62.3	6.0	77	62.2	8.7	76	76.9	3.4	85	30.4	22.7	84
	8^3	60.2	7.1	74	62.6	10.7	81	81.4	4.0	90	31.6	22.9	83
	8^6	61.2	8.1	76	61.8	11.2	80	78.4	4.1	85	29.6	23.2	87
GO	9^4	55.8	5.8	70	60.9	8.9	75	77.4	3.7	85	30.6	22.8	85
	9^2	56.7	6.4	71	53.0	7.8	68	67.2	4.0	59	32.5	19.0	65
	9^3	55.0	6.8	69	55.0	8.5	70	72.4	3.4	74	34.2	20.4	67

Note: The index figures are coded as follows: for raw stock, I_R; for grey yarn, I_{Grey}; for bleached yarn, I_{Bl}; for yarn dyed after bleaching, $I_{B\&D}$

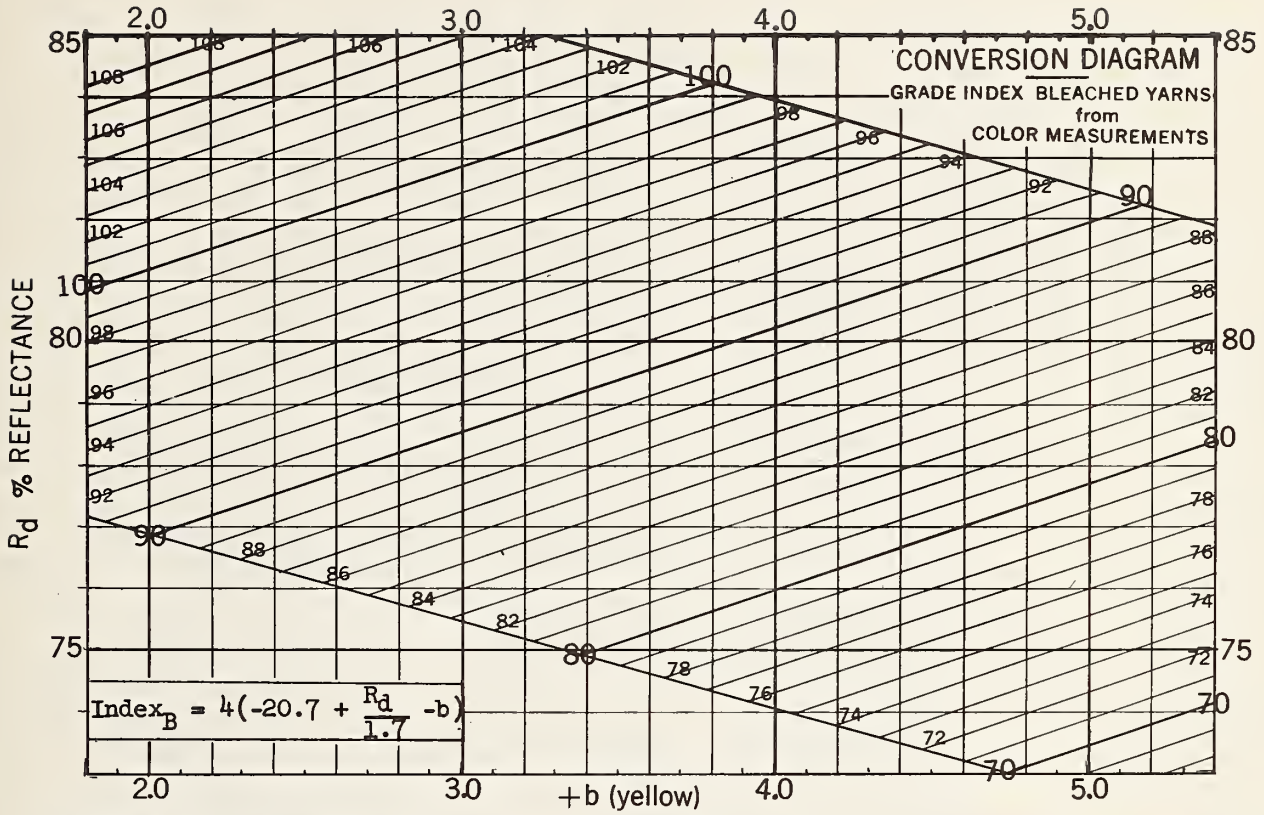

Figure 9.--Diagram (and formula) for Converting R_d and b measurements of Bleached Yarns (22s) to a Bleached Yarn Grade Index, 70 through 108.

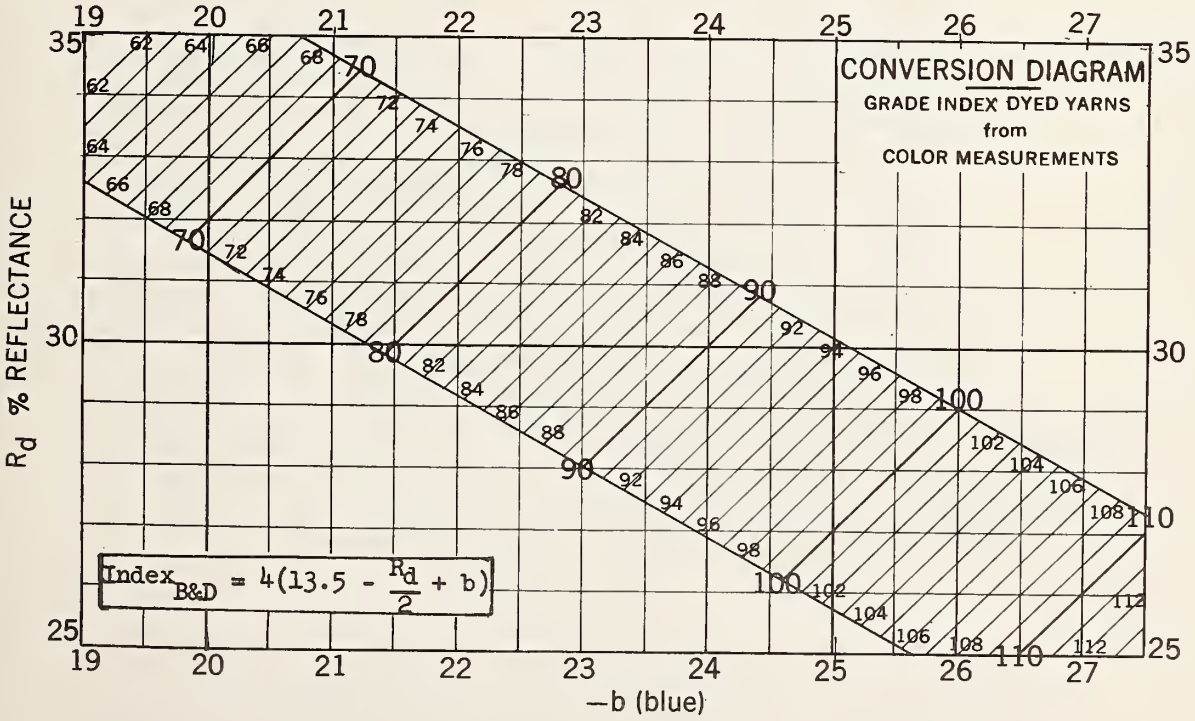

Figure 10.--Diagram (and formula) for Converting R_d and b measurements of yarns dyed Blue after bleaching to a Dyed Yarn Grade Index, 62 through 112.

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